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Time for commercializing non-food biofuel in China

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ABSTRACT

The booming automobile in China has added additional pressure on the country that needs to import almost 50% of its oil. Non-food-based biofuel is a viable fuel alternative for cars. China already has the required-foundation to commercialize non-food-based biofuel. Chinese crop straw and stock, energy crop, and woody biomass that could potentially be converted into energy are projected to be 700 million toe (ton of oil equivalent) in the near future. Meanwhile, Chinese food-based ethanol fuel industry ranks as the world's third after United States and Brazil. Several non-food-based ethanol plants are constructed or under constructed, one of which has been licensed. However, more efforts should be directed to commercializing non-food-based biofuel, including industrialized feedstock, strengthening key technology research, supporting private enterprise, and E10 upgrading to E20. The enormous increase in private ownership of car must compel China to commercialize biofuel.

Contents

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1. Introduction

Non-food-based biofuels have been developed because food-based biofuels have some drawbacks. Food-based biofuels, which are made from food crops such as corn, wheat, may help to improve energy security. However, skepticism and criticism for food-based biofuels have increased lately. The sudden rise in demand for food-based biofuels has possibly driven up food prices, and created indirectly a new world famine, as crop lands are used for fuel instead of food [1]. Moreover, the food-based biofuel cannot produce enough without threatening biodiversity [2]. Of course, the biggest skepticism revolves around CO_2 emission. When taking emissions from production and transport into account, life cycle assessment from food-based biofuels frequently exceeds those of traditional fossil fuels [3,4]. Non-food-based biofuels can help solve these problems and can supply a large proportion of our fuel supply sustainably, affordably, and with greater environmental benefits [5,6]. For example, cellulosic ethanol can reduce greenhouse gas emissions by around 60% when compared with fossil petroleum [3].

The booming car industry in China is calling for commercialization of non-food-based biofuel. In the first half of 2009, China's total car sales rose to 6.1 million, up 17.7% from the previous year [7]. This outpaced the United States where passenger car sales plunged to 4.8 million in the same period [8]. And the car craze here has just begun. In the future, with just 6 automobile owners per 100 household in China [9], compared with average 228 autos per 100 household in the US [10], the potential for growth of China's car market is enormous. This has, of course, for the global automakers the principal growth potential as they struggle with falling demand in North American and other markets. However, the spectacular emergence of automobile consumption has intensified China's affair with oil. International Energy Agency (IEA) project that China's oil demand for transport will quadruple between 2005 and 2030, contributing more than two-third of the overall increase in Chinese oil demand [11]. However, the oil R/P (reserves to production ratio) of China is only 11.1, whereas the global oil R/P is 42.0 at the end of 2008, according to *BP statistical review of world energy June 2009* [12]. How to fuel the growing number of vehicle in the street of China is a gigantic challenge for both China and the world. Commercializing non-food-based biofuel is a viable alternative fuel source to petroleum to fuel car.

To assess this viability requires an understanding about demand of biofuel, biomass resources, and the biofuel industry in China. On this basis, adequate policies recommendations for commercialization of non-food-based biofuel can be given as we shall show in the following.

The paper is organized as follows. The following section provides a short introduction to the oil demand and supply, and a brief overview of car sales in China. The next section surveys the biomass resources in China, including crop straw and stock, energy crop, and woody biomass. Section 4 analyses the biofuel industry in China. In Section 5, some recommendations are provided to commercialize biofuel in China. Our conclusion is that it is urgent to commercialize biofuel to fuel the skyrocketing car usage in China.

2. Oil demand propelling biofuel commercialization

Biofuel technology is nothing new. It was originally developed in the beginning of 20th century. The low oil price and abundant oil supply for most of history have restricted its technological advance and commercialization [13]. Sufficient and low price oil block commercialization of biofuel. Thus it is impossible to commercialize biofuel in the countries with rich in oil reserves, such as Venezuela and Saudi Arabia. Not so fortunate countries such as Brazil and USA have been driven to commercialize biofuel. Brazil has used sugarcane-based ethanol since the 1920s, when the automobile started to be introduced there. German submarine attacks threatening oil supplies in the Second World War, caused ethanol fuel production and consumption in Brazil to increase sharply. However, cheap oil after the end of that caused gasoline to dominate fuel consumption, ethanol fuel only being used occasionally. The oil crisis of 1970s caused oil shortages and high oil price. As Brazil imported about four-fifth of its oil in 1970s, the oil shortage and fluctuation of oil price significantly impacted its economic development. In response to oil crisis, the Brazilian government began to promote ethanol fuel [14]. Brazilian government mandated blending ethanol with gasoline, varying from 10% to 25% [15]. After nearly 30 years, Brazil has succeeded becoming the world's second largest producer of ethanol fuel and the world's largest exporter. In 2008, Brazil produced 24.5 billion liters of ethanol fuel, 37% of the world's total ethanol production used as fuel [16]. Similarly, the soaring oil price and increasing oil import have propelled the United States to heavily investment in corn-based ethanol and to become the first largest producer and consumer of ethanol fuel in the world [17]. In 2008, the United States produced 34.1 billion liters of ethanol fuel, ranking it the world's primary producer of ethanol fuel. The US together with Brazil accounted for 89% of the world's production in 2008 [16]. Here, we review the oil supply and demand in China to show the fundamental driving factor behind biofuel commercialization.

2.1. Expanding the gap between oil supply and demand in China

2.1.1. An overview oil status in China

Historically, China barely produced any oil in 1949, when the People's Republic of China was established. The country became oil sufficient in 1963 thanks to the discovery of the Daqing oil field in Heilongjiang Province, Northeast China. Subsequently other fields such as the Shengli oil field of Shandong Province, Zhongyuan oil field of Henan Province, and Dagang oil field of Tianjin City were developed. The US-led embargo isolated the Chinese oil industry from 1950 to 1970, preventing it to sell oil on the world market. When allowed to do so, China reactivated its links with industrialized countries by exporting oil. China's oil export peaked in 1985, with nearly 35 million tons [18] (see Fig. 1).

However, China is geologically oil-poor. At the end of 2008, the oil R/P in China was 11.1, far below the world average of 42.0 [12]. According the *BP Statistical Review of World Energy-2005* and *-2009*, China's proved reserves of oil remained level: 2.2 billion tons at the end 1984 and 2.1 billion tons at the end of 2008 [12,18]. Moreover, proved oil reserves in China only amount to 1.2% of the total world proved oil reserves at the end of 2008 [12] (see Fig. 2).

Currently, roughly 85% of the Chinese oil production capacity is located onshore. The Daqing and Shengli oil field are China's first- and second-largest oil field. However, both fields have been heavily tapped since the 1960s, and are expected to decline significantly in output in the coming years. Recent exploration and production activity has focused on onshore oil and natural gas fields in western

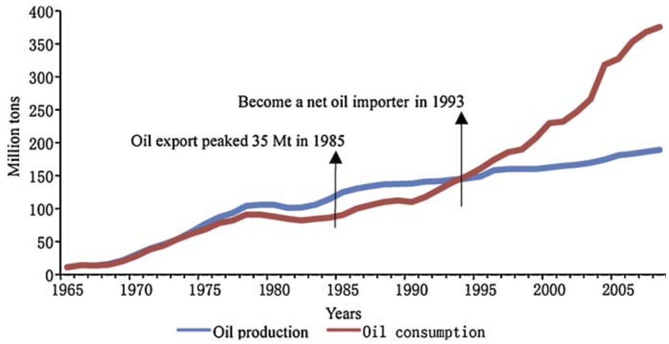


Fig. 1. Domestic oil production and consumption from 1965 to 2008 in China.[12,18].

interior provinces such as Xinjiang, Sichuan, Gansu, and Inner Mongolia as well as the offshore areas of Bohai Bay and the South China Sea [19].

2.1.2. Oil supply and demand

No significant increase in oil production has occurred lately in China. Domestic oil production hovers around 180.8 million tons in 2005, 183.7 million tons in 2006, 186.7 million tons in 2007, and 189.7 million tons in 2008 [12]. China's 11th Five-Year Plan for Social and Economic Development (2006–2010) projects annual oil production over the five years (2006–2010) to remain at a level between 185 and 195 million tons [20], notwithstanding the traditional bias in Five-Year Plans for over-optimistic production increases. The static oil-production projections reflect the geological realities of China's mature oilfields.

On the contrary, China's oil demand has been increased consecutively since the 1978 economic reform and open door policy. China's booming economy, which has averaged annually a nearly 10% growth for the last three decades, requires massive levels of energy to sustain its growth. Though China relies on coal for most of its energy needs, it is the second-largest consumer of oil in the world behind the United States [12]. Driving the rapid economic growth, increasing oil demand resulted in China to become net oil importer in 1994 [18] (see Fig. 1). As shown in Fig. 1, the difference between oil production and consumption has diverged enormously in China since 1993. From 2000 to 2007, China's oil production has increased by 16.7%, while China's oil consumption increased by 63.3% during the same period [18,21].

Given the poor oil resources and limited domestic supply, imports have been China's principal means to satisfy a growing demand. Indeed, China needs to increase oil imports yearly, as its own crude oil output growth fails to outpace consumption demand in recent years. As shown in Fig. 1, China's oil import has increased from 0 to 50 million tons between 1994 and 1999, whereas oil import has soared from 50 to 100 million tons between 2000 and 2003, jumping from 100 to 150 million tons between 2004 and 2005. Currently, about half of China's oil consumption is imported

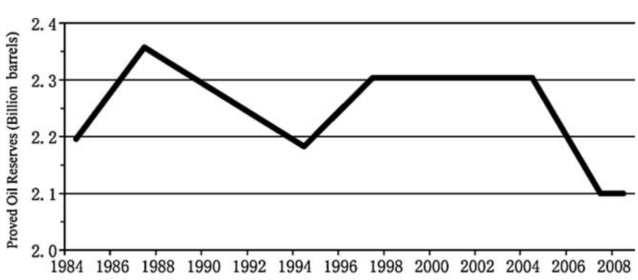


Fig. 2. China's proved oil reserves from 1984 to 2008.[12,18].

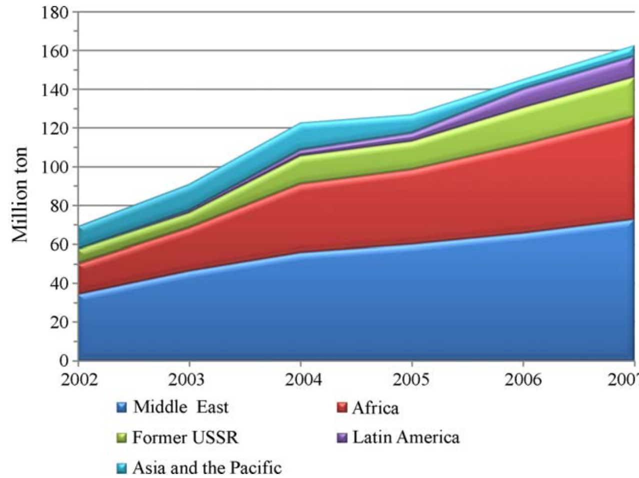


Fig. 3. Geological distribution information of China's oil import.[23].

[12]. It is projected in the *World Energy Outlook 2007: China and India Insights* that 60% of China's oil consumption has to be imported by 2030 [11]. However, such estimation may be too conservative. In *World Energy Outlook-2008*, IEA adjusted their prediction that China's oil imports will account for almost 75% of its total oil consumption by 2030 [22].

The Middle East, Africa and former USSR are the main sources of China's imported oil [23] (see Fig. 3). The Middle Eastern region as a whole has quite a volatile geopolitical situation as it has seen a number of conflicts over past few decades. Geopolitical factors have become an indispensable part of the oil trade, and oil diplomacy has become an important tool to cope with geopolitical risk and ensure national oil security. China has tried to diversify its oil importing sources to find more sustainable supply. As shown in Fig. 3, the percentage of Middle Eastern oil of the total import oil has decreased, even though the total volume of Middle East oil has increased. Dependence on Middle East oil will not change in the near future, as the Middle East holds about 60% of the world's proven oil reserves. Hence, China's oil import has become a chronic problem, fundamentally threatening the country's energy security.

2.2. Soaring oil price

The price of crude oil in 2003 traded in a range between $20 and $30/barrel. Between 2003 and 2008, prices steadily rose, reaching $60/barrel in August 2005, breaking $100/barrel in January 2008. A steep rise in the price of oil in 2008, culminated in an all time high of $147/barrel on July 11, 2008 [12] (see Fig. 4).



Fig. 4. Sketch map of oil price from January 1980 to June 2009 (the graph is based on the nominal price of oil).[12].

The soaring oil price has been attributed to a series of factors, including reports from the BP, IEA, EIA (Energy Information Agency of United States) and other agency showing a decline in oil R/P [21,24,25], worries over Middle East tension, and financial speculation (in September 2008, a study of the oil market by Masters Capital Management was released which stated that over $60 billion was invested in oil during the first 6 months of 2008, helping drive the price per barrel from $95 to $147/barrel) [26]. However, the main long-term fundamental reason of soaring oil price is the demand over the supply. According to *BP statistical review of world energy June 2009*, the average annual growth in oil consumption reached 14.71% from 1998 to 2008, whereas the average annual oil production only rose by 11.26% [12]. The downturn of oil price in late 2008 and early 2009 has been mainly attributed to the shrinking demand for energy caused by the global financial crisis of 2008. However, economic recovery caused the oil price to surge back again, about $70/barrel in May 2009 (see Fig. 4).

The coming demand for oil comes from the developing world. The population growth, improved living standards, rapid urbanization, and accelerating industrialization in developing countries drive up energy use, most often of oil. China alone accounted for 52% of the world energy consumption growth in 2007 [21], and for about 75% of the global energy consumption growth in 2008 [12]. It has to be kept in mind that the global oil production will decline at some point. Although the exact time at which global production will peak is contented, there are now very few parties who do not acknowledge that the concept of a production peak is valid [27]. The increasingly expanded gap between global oil demand and supply will be a substantial factor in future oil pricing. It should be pointed out that a high-quality and low-cost oil field is first exploited, remaining reserves are increasingly more technically difficult to extract. Oil supplies in the future will come more and more from smaller and more difficult fields, meaning that future production requires more investment and therefore is more expensive.

Eventually, reserves will only be economically feasible to extract at extremely high prices. Even if total oil supply does not decline, the easily accessible sources of light sweet crude are almost exhausted and in the future the world will depend on more expensive unconventional oil reserves and heavy oil. A prominent example of investment in non-conventional sources is the Canadian oil shale. They are a far less cost-efficient source of heavy, low-grade oil than conventional crude, but when oil trades above $50–60/barrel, the oil shale becomes attractive to exploration and production companies [28]. In a word, oil prices will continue to be high and rising.

2.3. Car boom exacerbating the oil demand in China

Oil demand in China will be boosted by rapid economic growth, especially the sharply and enormous growth in number of cars. From 1990 to 2008, the market for passenger cars grew by a factor of 18 in China, from 0.51 to 9.38 million (see Fig. 5). China's car market has overtaken Japan to be the second-largest car market in the world with sales of 7.28 million vehicles in 2006.

In the first half of 2009, China's total car sales rose to 6.1 million [7], which outpaced the United States where passenger car sales plunged to 4.8 million in the same period [8], making China become the world's biggest auto market. Moreover, China's vehicle sales have reached 10-million cars for the first time ever, with 10.9 million automobiles sold in the first 10 months of 2009, up 37.8% over the same period last year [7]. This has consolidated its top position in the global automobile market.

However, the Chinese love affair with car ownership has just begun. The income elasticity of vehicle ownership in 45 countries over 1960–2002 shows that the vehicle ownership is fastest

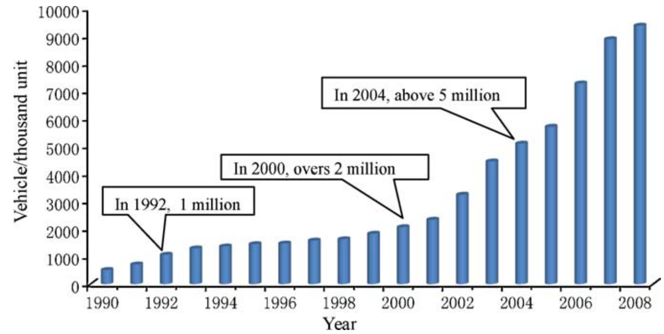


Fig. 5. China motor vehicles sales from 1990 to 2009.[9].

growth when the income levels increase to the range of $3000–10,000, i.e. ownership increases twice as fast as per-capita income [29]. In 2008, the Chinese per-capita income is US $3267 (30,067 billion Yuan [GDP]/6.948 [average exchange rate between Yuan and US dollar in 2008])/1324.65 million [population] = US $3266.8/person]), according to the National Bureau of Statistics of China [30]. It implies that future growth of automobiles in China will dazzle. If the rate of vehicle ownership in China is only at levels experiences by Japan and Western Europe in the mid-1970s, i.e. about 27 vehicles per 100 person, Chinese vehicle stock will increase to 390 million. That is more than the American vehicle stock [29]. It is a development that provides confidence and hope to global automakers to offset their losses in Western markets. In the long future, with just 6 automobile owners per 100 household in China [9], compared with average 228 autos per 100 household in the US [10], the potential for growth of China's car market is enormous. However, the spectacular car boom, which closely mirrors the rising middle-class, has driven China to be the second largest consumer of oil after the US in the world. In the future, China's oil demand for transport will almost quadruple from 2005 to 2030, contributing more than two-thirds of the overall increase in Chinese oil demand, according to IEA estimation [11].

3. Biomass resource for biofuel commercialization

According to the *Medium and long-term development plan for renewable energy in China*, biomass energy resources in China include mainly crop straw and stalks, energy crops, woody biomass for energy, animal manure, organic effluent from industry, municipal wastewater, and municipal solid waste. Of about 600 million tons of crop straw and stalks produced every year, nearly 300 million tons, equivalent to about 105 million toe, can be used as fuel. Of about 900 million tons of waste from forestry and forest product processing available every year, nearly 300 million - tons, equivalent to about 140 toe can be used for energy production. In addition, there are large areas of marginal lands in China that can be used to cultivate energy crops and plantations. Biogas and municipal solid waste are also biomass resources with good potential for development. Presently, the nation's total biomass resource that can potentially be converted into energy is about 350 million toe. With social and economic development, the biomass resource that could potentially be converted into energy is expected to increase to 700 million toe in the near future [31]. Due to the crop straws and stalks, energy crops and woody biomass are more potential feedstock for biofuel commercialization, our report focuses on these biomass resources.

3.1. Crops stalks and straw

Crop stalks and straws are mainly distributed in Hebei, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Jiangsu, Henan, Shandong,

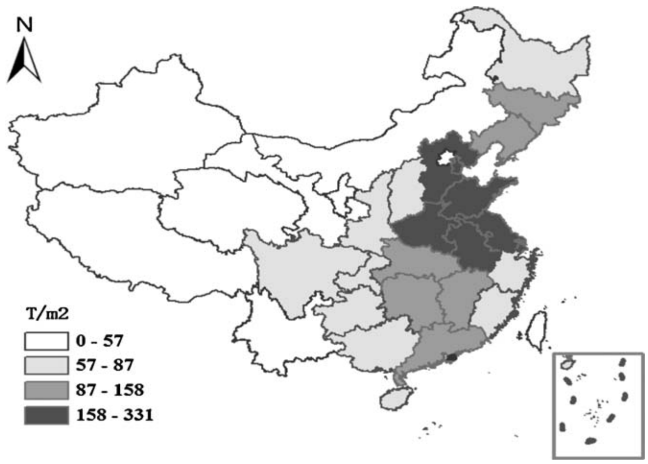


Fig. 6. Output of crop stalks and straws per unit land in China.[32,33].

Hubei, Hunan, Jiangxi, Anhui, Sichuan, and Yunnan are major grain producing areas in China. Considering the crop stalks and straw output per hectare, seven provinces rank the first place: Shandong, Henan, Jiangsu, Anhui, Hebei, Shanghai, Jilin (see Fig. 6).

The total crop stalks and straws were around 600 million tons in 2007, according to the *China agriculture yearbook-2008* [33]. Of this, about 3 million tons, i.e. about 105 million toe could be used as bioenergy resources [32]. It is projected that total crop production is about 780 million tons, of which about 400 million - tons, i.e. about 140 million toe can be used as bioenergy resources by 2010 [34]. The total crop production is projected to be almost 900 million tons, about 450 million tons, i.e. about 158 million toe can be used as bioenergy resources by 2015 [32].

3.2. Energy crops

Energy crops are plants that are cultivated for the purpose of producing non-food energy. Examples include not only plants that are used to produce biofuel, but also plants that are grown for burning wood. A large number of barren hills, slopes, marginal lands, and saline-alkali soil in China are not suitable for growing food crop, but suitable for growing energy crops with characteristics of salt endurance, drought resistant. Although there are about 200 types of energy crops, four types have been exploited or under exploited to produce biofuel in China [34].

3.2.1. Sweet sorghum

Sweet sorghum will thrive under drier, warmer conditions and saline-alkali soil than many other crops. Sweet sorghum has been utilized by the ethanol industry for quite some time because it yields approximately the same amount of ethanol per liter as corn. As new generation ethanol processes are studied and improved, sweet sorghum's role may continue to expand.

Currently, sweet sorghum acreage in China is small and scattered. However, a number of provinces are suitable to cultivate sweet sorghum, such as Beijing, Tianjin, Hebei, Inner Mongolia, Henan, Shandong, Liaoning, Jilin, Heilongjiang, Shaanxi, and Xinjiang. Currently, there is about 10 million ha with saline-alkali in China [33]. If one-fifth of the 10 million ha of saline-alkaline land is used for growing sweet sorghum, and if the output in the saline-alkali soil is only half of normal soil, the output of sweet sorghum would be 60 million tons/year, producing 3.5 million tons ethanol [34].

3.2.2. Sugar cane

Sugar cane is perennial herbs of tropic and sub-tropic, and can be used for sugar and the production of fuel ethanol. There are three ways for production of fuel ethanol from sugar cane in China. First is from the molasses, which is a byproduct of the processing of sugar cane. In 2006, the output of molasses totaled 3.4 million - tons, which can produce 800,000 tons of ethanol. Second is to improve per hectare output of sugar cane. At present, the average output of sugar cane is about 65 tons/ha. Recent research shows the output of sugar cane can reach more than 90 tons/ha [35]. Advanced technology of sugar cane used on an expanded scale will increase biofuel feedstock. Third is to exploit the wasteland suitable for sugar cane. It is estimated that about 650,000 ha of wasteland are suitable for sugar cane growth in Guangxi, Guangdong, Hainan, and Yunnan. If half of the wasteland is used for sugar cane and per hectare output 65 tons of sugar canes, more than 1.3 million tons/year of sugar canes could be produced [32].

3.2.3. Cassava

Cassava is a woody shrub of the Euphorbiaceae native to west Brazil that is extensively cultivated as an annual crop in tropical and subtropical regions for its edible starchy tuberous root, a major source of carbohydrates. Guangxi, Guangdong, Hainan, Fujian, Yunnan, Hunan, Sichuan, Guizhou, Jiangxi and nine other provinces are suitable for cassava growth. Total output of cassava in China is about 7 million tons in 2007, of which, Guangxi and Guangdong accounted for about 90% of the total output in China.

There are about 133 million ha of unused land and barren land in Guangxi, Guangdong, Hainan, Fujian, Yunnan, suitable for cassava cultivation. If one fifth of this 133 million ha land was cultivated for cassava and the output of cassava was 30 tons/hectare, the total output of cassava would be 80 million tons, and the total output of ethanol would 10 million tons [32].

3.2.4. Sweet potato

The sweet potato is a dicotyledonous plant that belongs to the family Convolvulaceae. With the characteristic of withstanding drought, wind, and pests, sweet potato can grow on marginal land. The output of sweet potato in China totaled 100 million tons in 2005, ranking it first in the world. It is estimated that storage loss accounted for about 20% of the total output. If timely producing to biofuel after harvest, it would produce about 2.5 million tons of ethanol, and prevent those 20% of storage loss [32].

At the end of 2008, China had approximately 122 million ha of arable land, covering 13% of its territory. This amounted to 0.27 ha per capita, less than 40% of the world per capita average, one-eighth the US level, and one-half the Indian level [36]. The limited arable land is destined to cultivate food. So the above mentioned energy crops must be cultivated on barren land, saline-alkaline land, and land reclaimed from mining and oil extraction. It is estimated that about 54 million ha of barren hill land and 100 million of saline-alkali soil, sand, as well as reclamation land of mine and oilfield, are suitable for growing energy crops [37].

3.3. Woody biomass for bioenergy

There are about 400 oleiferous tree species in China. 200 of these species have a 15–50% oil content in the fruit, and 50 a 50–60% oil content in the fruit, including Jatropha curcas, Pistacia chinensis, Shiny-leaved yellowhorn, Light skin tree, Tea-oil, Tung tree, Chinese tallow, and Walnut [38]. However, most have not been exploited except for the tea-oil, tung oil trees, walnut and other resources, which have been developed for food oil and industrial feedstock. The development of biofuel resource has focused on six species, i.e. Jatropha curcas, Pistacia chinensis, Betula trees, Shiny-leaved yellowhorn, Tung tree and the Chinese tallow tree. These six species are estimated to more than 1.35 million ha in China. The fruit output of these six species is more than 1 million ton/year. If 50% of fruit of these species was

Table 1
The cost and sales of the four pilot ethanol plants in China.

Company	Material	Designed capacity (thousand t/a)	Material cost (Yuan/t)	Ethanol cost (Yuan/t)	Ethanol sales (Yuan/t)	Loss (Yuan/t)
BBCA Biochemical Co., Ltd.	Corn	320	~1720	7095–8109	6359	736–1750
Jilin Fuel Alcohol Co., Ltd.	Corn	300	~1610	6641–7590	6359	282–1231
Herein Huarun Alcohol Co., Ltd.	Corn	100	~1570	6476–7401	6359	117–1042
Tianguan Group Co., Ltd.	Wheat	300	~1550	6394–7307	6359	35–948

[41].

used to produce bioenergy, the output of biodiesel would be more than 200,000 tons. In addition, firewood, pruning shrub, remains from forestry production process also can be used as feedstock of biofuel [37].

With a total 300 million ha of firewood forest, the output of firewood reached 80–100 million tons/year in China. China's shrub land totaled 450 million ha, producing about 100 million tons of biomass per year. Afforestation in recent years has created about 70 million ha new forested acreage, harvesting nearly 100 million tons/year of biomass. Therefore, wood for biofuel is over 300 million tons, equivalent to 140 million toe in China [37].

4. Biofuel industry

The Biofuel industry in China focuses on ethanol production. The output of ethanol totaled 1.45 million tons in 2007. Corn-based ethanol accounted for about 80% of the total ethanol fuel, wheat-based ethanol for the remaining 20%. Compared with ethanol production, other biofuel production is small. Total biodiesel production was only about 300,000 tons in 2007. The central government regulates the biofuel market. Stated-owned enterprises almost monopolize biofuel production. Biofuel is sold only to the two stated-owned oil companies, China Petroleum and Chemical Corporation (Sinopec) and the China National Petroleum Corporation (CNPC) for blending with gasoline [39].

4.1. Food-based ethanol industry

Chinese fuel ethanol originally developed in order to tackle surplus corn stocks in the beginning of this century. China's corn and wheat surplus has grown steadily, with annual grain production reaching 500 million tons since 1998–2002. In 2001, Jilin province, a leading Chinese corn producer, warehouses bulged with stocks after several years of good corn crops, leading corn prices to plunge to 10-year lows. The grain stockpile in Henan Province, a leading wheat producer in China, totaled 35 million - tons, reflecting an annual wheat surplus of 4–5 million tons. In 2001, the central government decided to invest in four large-scale ethanol production pilot projects in the leading grain production areas to "eat" surplus corn stock. Herein Huarun Alcohol Co., Ltd., located in Heilongjiang Province, Jilin Fuel Alcohol Co., Ltd., located in Jilin, and BBCA Biochemical Co., Ltd., located in Anhui are based on corn. Tianguan Fuel ethanol Co., Ltd., located in Henan is based on wheat. The total output of corn-based ethanol is about 720,000 tons, whereas the total output of wheat-based ethanol is about 300,000 tons.

Meanwhile, increasing oil import and soaring oil price since 2003 have propelled China's policy makers to view ethanol fuel as an essential and strategic component of a secure energy security and diversified energy [40].

To support the above mentioned pilot ethanol plants, five effective policies have been implemented. First, the central government directly invested 480 million Yuan (US $71 million) in the four demonstration plants. Second, the Value Added Tax (17%) of these plants has been removed. Third, Consumption Tax of ethanol blended gasoline (5%) has been removed. Forth, the central government provides direct financial subsidy for their feedstock. Fifth, the central government also provides direct financial subsidy for the losses incurred by the four demonstration plants, as the ethanol price did not cover the production costs (see Table 1). It is estimated that the removal of the Value Added Tax and Consumption Tax totaled 190 million Yuan (US $28 million), and the direct financial subsidy totaled 2 billion Yuan (US $294 million) for these four plants from 2002 to 2008 [40].

To cultivate the consumption market of fuel ethanol, China has promoted since 2002 a mixture of gasoline (90%) and ethanol (10%) on a pilot basis in five cities in the central and northeastern regions: Zhengzhou, Luoyang and Nanyang (in Henan Province) and Harbin and Zhaodong (in Heilongjiang Province). Authorized by the State Council in February 2004, extended pilot work has been carried out in five provinces, Heilongjiang, Jilin, Liaoning, Henan and Anhui and 27 cities in Hebei, Shandong, Jiangsu and Hubei to experiment with the use of bio-ethanol for automobile fuel (see Fig. 7). The gas stations in the pilot areas were required to switch fully to the cleaner-burning mixture by the end of 2005. These supporting policies have driven China's ethanol fuel production to rise from nearly zero in 2002 to 1.9 million tons in 2008 [16].

4.2. No-food biofuel

Soaring food price and shortage in grain stock in 2006 led policymakers toward to non-food-based biofuel. The surging demand for biofuel was blamed for price hikes in the food market and for shortages in grain stocks. Although rivalry between food and fuel producers for grain is not limited to China, the problem is particularly acute in China where 7% of the world's arable land to feed about 20% of the world population. Concerning about the impact on food self-sufficiency has slowed development of food-based biofuel industry. Policymakers hold that biofuel in China should neither impact on the people's grain consumption, nor should it complete with grain crops for cultivated land. China banned the further use of grain for ethanol production to ensure

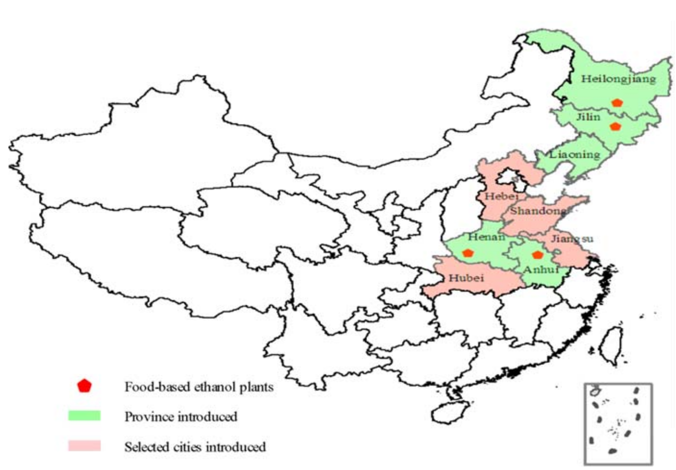


Fig. 7. The distribution of ethanol production in China.[39,40].

that grain was available for food in December 2006; meanwhile, the government encouraged the non-food-based biofuel development [40]. According to the 11th Five-Year Plan of renewable energy, the barren land in northeast China and Shandong Province are designated to plant sweet sorghum to develop sorghum-based biofuel. The barren land in Guangxi Province, Chongqing Province, Sichuan Province and other places are designated to grow cassava and thus develop cassava-based biofuel. Meanwhile, China will strengthen the cellulosic biofuel research and support cellulosic biofuel demonstration project. The plan expected that non-food-based fuel ethanol will be 2 million tons in China by 2010 [42].

4.2.1. Cellulosic biofuel

In 2006, China National Cereals, Oils and Foodstuffs Corp. (COFCO), a gigantic state-owned enterprises, has made out an ambitious plan of cellulosic biofuel. COFCO sighed with Novozymes, a world's leading producer of enzymes, agreement to construct a pilot project with production capacity 10,000 tons/year in Zhaodong County, northeast China's Heilongjiang Province. The small-scale testing with capacity 500 tons/year has been proved success in 2006. However the next scaling-up test to capacity 5000 tons/years was not, according to its cooperation partner Novozymes. However, COFCO did not give up. COFCO, Sinopec and Novozymes signed a new agreement to advance cellulosic ethanol technology in 2009 [43].

In addition, the Tianguan Group Co., Ltd., constructed a pilot cellulosic ethanol production line, with a capacity of 300 tons/year. The enterprise plans to invest another production line with a capacity of 1000 tons/year based on the experiences and lessons from the 300 tons/year production line. Moreover, a high-tech research project, the 863 Program named "technology of crop straw producing the ethanol" created a pilot production line with capacity 600 tons/year in East China University of Science and Technology (located in Shanghai). However, the production line is not operating smoothly because of feedstock problems [44].

4.2.2. Cassava

In 2006, COFCO signed an agreement with the Guangxi Province government to construct a cassava-based ethanol plant. The pilot project has been approved and supported by National Development and Reform Commission (NDRC), a watchdog of Chinese economy and energy [45].

A 200,000 tons/year cassava-based fuel ethanol demonstration project of COFCO Guangxi Bio-Energy Co., Ltd., in Beihai, Guangxi Province, is China's first operating fuel ethanol plan using feedstock other than grain. The project is in line with the government effort to open up new ways for China's non-grain-based ethanol sector. It got fifth production ethanol license (the other four licenses are in food-based ethanol as mentioned earlier), meaning it gets financial subsidies and tax reduction. Construction started in December 2006 and a pilot operation succeeded in 2007. It is a part of COFCO's efforts to develop the non-grain-based fuel ethanol business. COFCO has applied for 34 national level invention patents for the project, nine of which have been granted. The first phase plan of the pilot project is 200,000 tons, the second phase plan 300,000 tons, and the long term plan over 1 million - tons. With designed capacity of 200,000 tons, the pilot project needs 1.5 million tons of raw cassava, which is equivalent to the cassava output of 2.7 million ha. However, the total acreage allocated to cassava is only 1.0 million ha in Guangxi Province. Feedstock has therefore become one of the principal barriers for the pilot project to succeed [45].

It is reported that there are several investment plans for cassava-based ethanol (see Table 2). However, no licenses have been given to date to implement any of them.

Table 2
Several potential cassava-based ethanol projects.

Company	Capacity (thousand/a)	Location
Beihai Guofa	100,000	Beihai City, Guangxi Province
Hannai Yedao	100,000	Haikou City, Hainan Province
Hualing	500,000	Guangdong Province
Qingyuan Heli Huanneng	20,000	Qingyuan City, Guangdong Province

Source: [41].

4.2.3. Sweet sorghum

Currently, sweet sorghum-based biofuel has not been a success for several reasons. One reason is technically immature. Jilin Fuel Ethanol Co., Ltd., invested 65 million Yuan (US $9.6 million) to construct a sweet sorghum-based ethanol demonstration project with a production capacity of 3000 tons/year in Dongtai City, Jiangsu Province, Southeast China. The project uses solid-state fermentation technology. In 2007, the plant started a trial operation. However, the ethanol content is so low (only 20%) that it cannot be used as fuel. In March 2007, COFCO in cooperation with BP began to construct pilot plants of sweet sorghum in Huanghua county of Hebei Province, Xinyang county of Shandong Province and Wuyuan Country of Inner Mongolia. However, in April 2008, COFCO declared that they would abandon these.

In contrast to the above mentioned failures in state-owned enterprise, those in private enterprises are mainly attributed to lack of government support. The Shandong Binzhou Guanghua Biology Group is the first producer of sweet sorghum-based ethanol in China. In 2005, the company invested 25 million Yuan (US $3.7 million) into a sweet sorghum-based ethanol project with a production capacity of 5000 tons/year. Moreover, the company has independent intellectual property rights of sweet sorghum-based ethanol. Its new process technology has been approved to substantially decrease the production cost of ethanol fuel. However, because it is a private company, the enterprise has not received financial subsidy and tax reduction from the government. The company suffered losses of about 500–1000 Yuan (US $74–147) on each ton of ethanol. As a result, the company had to close down [45].

5. Recommendations

Non-food-based ethanol fuel industry in its infancy needs supporting policies to ensure feedstock supply, to lower the cost, and to cultivate market.

5.1. Industrializing feedstock

Feedstock supply is a key factor in limiting biofuel development in China [45,46]. Indeed, cultivating energy crops will be a long term challenge for non-grain-based ethanol. With 20% of the global population but only 7% of world's farmland, China grain supply is under long-term pressure from a growing population with, rising incomes, while industrialization and urbanization gradually nibble away at cultivated land. To avoid biofuel feedstock competition with food, the biofuel feedstock must be grown on non-arable land, marginal land, barren land and other land not suitable for grain growth. As mentioned earlier, about 54 million ha of barren hill land and 100 million ha of saline-alkali soil, sand, as well as reclamation land of mine and oilfield are suitable for cultivation of energy crops.

Large-scale develop of energy crops in these barren lands needs heavily initial investment, advanced technology, and higher capacity to respond to market risks, which are beyond the current scattered agriculture production model. To achieve large-scale

development of energy crop, industrialized agricultural production is a viable choice. Meanwhile, large-scale feedstock companies can ensure feedstock more stable and reliable feedstock supply than incidental farmers.

5.2. Breakthrough key technology

Technology is essential to make non-food biofuel more cost-effective. For example, the high cost of cellulose enzymes caused to non-food-based biofuel to be more expensive than food-based biofuel. Unlike food starch, non-food feedstock needs cellulose enzymes to obtain glucose and other five- and six-carbon sugars. Aimed to reduce the cost of making cellulase, Genencor and Novozymes each conducted four-year research and development projects with the Department of Energy's National Renewable Energy Laboratory since 2000. The two companies announced huge reductions in the cost of making the enzyme, from more than US $5.00/gal of ethanol at the start of their projects to less than US $0.20/gal at the end. Without such key technology breakthroughs, non-food-based ethanol will remain expensive [47].

China has mastered cassava-based ethanol technology by constructing the demonstration project in Guangxi Province, but liquefaction, saccharification, fermentation, separation process, and sterilization devices, it still lags behind international advanced levels. Cellulosic biofuel is still in the research stage, and a large of research effort is needed for industrial production.

5.3. From E10 to E20

As earlier mentioned, to support food-based ethanol development, the Chinese government mandated E10 (10% ethanol and 90% gasoline) in nine provinces. Such policy is inevitable and indispensable for promotion of ethanol consumption market. But E10 is not good enough.

In Brazil, support for ethanol consumption was provided by mandatory use of E10 in 1977. In 1982, the mandatory blend was adjusted to a 15% of ethanol and 85% gasoline (E15). In 1984, the mandatory blend was set as the 20% of ethanol and 80% gasoline (E20). In 2008, the mandatory blend was upgraded to E25 (25% ethanol and 75% gasoline) [15] (see Table 3). China should follow the example of Brazil upgrading from E10 to E20.

5.4. Support private enterprise to develop biofuel

The experiences of biofuel commercialization in Untied States and Brazil show that a supportive policy is a fundamental requirement for the biofuel industry [48,49]. The Chinese government has noticed that and taken a series of substantial supporting policies, which include direct financial subsidiary, tax exemptions and low-interest loans for capital investment from feedstock to production and consumption. However, all supporting policies are directed toward state-owned enterprise, whereas only a few of them are accessible by private enterprises. Currently, five licenses have been issued concerning biofuel production, three of them corn-based, one wheat-based, and one cassava-based. All factories belong to state-owned enterprises (see Table 4).

Table 3
Evolution of ethanol blend used in Brazil (1976–2008).

Year	Ethanol blend	Year	Ethanol blend
1931	E5	1999	E24
1977	E10	2003	E20–25
1982	E15	2005	E22
1984	E20	2008	E25
1993	E22		

Source: [15].

Table 4
Five licenses of biofuel in China.

	Company	Feedstock	Shareholder
1	Herein Huarun Alcohol Co., Ltd.	Corn	COFCO control 20%
2	Jilin Fuel Alcohol Co., Ltd.	Corn	China National Petroleum Corporation holds 55%, COFCO share 20%
3	BBCA Biochemical Co., Ltd.	Corn	China National Petroleum Corporation holds 60%, China Petrolem Chemical Corporation shares 20%
4	Tianguan Group Co., Ltd.	Wheat	COFCO is the largest stockholder, sharing 20%
5	COFCO Guangxi Bio-Energy Co., Ltd.	Cassava	COFCO control 100%

In some cases, lack of supportive policy is the main reason for failure of private enterprise investment in biofuel plants. As mentioned earlier, the experience of Shandong Binzhou Guanghua Biology Group, a producer of sweet sorghum-based ethanol in China illustrates this. Private enterprises should not excluded from biofuel commercialization. Instead, they should enjoy supporting polices comparative to those enjoyed by state-owned industries.

6. Conclusion

The booming car industry in China does and will expand the gap between oil supply and oil demand, resulting in more serious oil shortage and higher oil price in China. The oil shortage and high oil price call for non-food biofuel commercialization in China. Indeed, China already has the required foundation to commercialize non-food-based biofuel. It has great potential biofuel feedstock, including crop stock and straw, energy crops and woody biomass. The biomass resource that could potentially be converted into energy is expected to increase to 700 million toe in the near future. Using this to produce non-food-based biofuels will not only increase oil supply to fuel the increasing number of cars, but also slash carbon dioxide emissions. China is the world's third largest food-based ethanol producer and consumer after United States and Brazil. Several non-food-based ethanol plants are constructed or under construction, including one that has gained a license from NDRC. However, non-food-based biofuel commercialization, as any new industry, faces challenges and barriers, requiring a series of efforts to conduct smooth commercialization of biofuel smoothly. First, industrializing feedstock supply is needed to realize the potential for Chinese biomass. Second, China must strengthen key technology research to slash production cost. Third, the current E10 should be upgraded to E20 to increased demand for biofuel. Finally, private enterprises should be accessed to government support policies.

China must step up efforts to commercialize non-food-based biofuel. Policymaker, entrepreneur, and scientist should not only see commercialization of biofuels as an alternative futuristic strategy, but also take the increasing in cars in China's street into the consideration—time is calling for biofuel commercialization.

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